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Trinity

by

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LOS ALAMOS NATL. LAB. LIBS.
3 9338 00317 1336

6.3.4. Capture Gamma and Contamination. Some of the features of the Trinity Test were due to the location of the point of burst near the ground. During the first fraction of a second an appreciable amount of gamma radiation, for points close to the burst, was due to neutron capture in the ground. No measurements bearing on this point have been made, so it will not be discussed further. Estimates of this effect have been made by Weisskopf, and calculations of Marshak[8,9] on the rate of neutron absorption in the ground are pertinent.

Because of the presence of the dust around the detonation point, a large region of the countryside was contaminated with fission products. This topic is discussed by Hirschfelder et al.[10]

A total of about 1% of the fission products was left in the crater and vicinity. The gamma activity due to this contamination is reported by Aebersold and Moon.[11]

6.4. Thermal Radiation

6.4.1. Total Radiation. The total radiation was measured by D. Williams and P. Yuster,[12] using a thermopile technique. They obtained a value of 3060 metric tons TNT equivalent for the total; the measurement was made at 10 000 yd.

6.4.2. Radiation Intensities—Space and Time Relations. There was no good measurement either of the brightness of the ball of fire or the illumination as a function of time at any distance at Trinity. Measurements of the brightness using the absolute density of fastax film and rough estimates of the temperature by means of a record obtained on a recording spectrograph indicate roughly solar brightness, with little variation as a function of time.[13] These measurements were admittedly unrealiable. The theoretical expectation had been that the temperature of the radiating surface should be several hundred thousands of degrees for the first few microseconds, drop to a minimum of about 4500° at about 15 ms,[5] increase for less than a second to 10 000° and then cool off more slowly. The minimum was corroborated, but the initial high temperatures were not found.

The theory of the radiating body was further developed.[5] The high temperatures initially seemed to be essential, and they were kept in the theory. The theory for the radiation after the first few milliseconds is not in a very good state, and here the "theory" was adjusted to give the correct total radiation as measured by Williams and Yuster.[12] At the Bikini Able test the existence of the extremely high temperatures was verified by measurements of Brian O'Brien.

In Fig. 7 the illumination as a function of time is presented. The ordinate is distance squared times "suns," where the sun ʘ, is a unit of illumination rather than brightness. The temperatures of the radiating surface are indicated along the curve. This curve calculates radiation intensities at all distances and times, insofar as atmospheric absorption can be neglected.

6.4.3. Incendiary Effects. Measurements on the incendiary effects were made at Trinity by Marley and Reines.[14] They found that no fires were started in wooden materials which were appreciably outside the fire zone, but that charring occurred to beyond 1000 yd. Fir timber was slightly scorched to distances of 2000 yd.

In an attempt to understand scorching and charring, let us consider a constant source of heat on a surface. It can be shown rather easily that the surface temperature is raised after a time by the amount $T_s = \frac{2}{\sqrt{\pi}} \; \frac{Q \;\; t}{K \, \rho \, C}$ *,

where Q = strength of heat source (cal/cm^2 s)
K = thermal diffusivity (cm^2/s)
ρ = density (g/cm^3)
C = specific heat (cal/g degree).

The above formula shows that the source strength comes in directly, whereas the time is a square root. It is thus relatively better to have an intense source for a short time. It seems reasonable to expect a scorching or charring process to have a temperature criterion, either occurring or not depending upon the temperature, and relatively unsensitive to application time.

******Sic.* **This equation and the following text appear as in the original report.**

Let us apply this formula to pine wood, using Fig. 7. The constants are taken as $K^2 = 1.4 \times 10^{-3}$, $\rho = 0.5$, and $C = 0.42$. Assuming that the value of $D^2\Theta$ is constant at 4.5×10^9 for 20 ms and then drops abruptly to zero, we get $\Delta Ts = 9.2 \times 10^8 °C/D^2$ (for distance in yards). This is for absorption of all of the radiant energy. If 400° C is selected as a charring temperature we get D = 1520 yd. This is about the limit to which there was an appreciable effect observed.

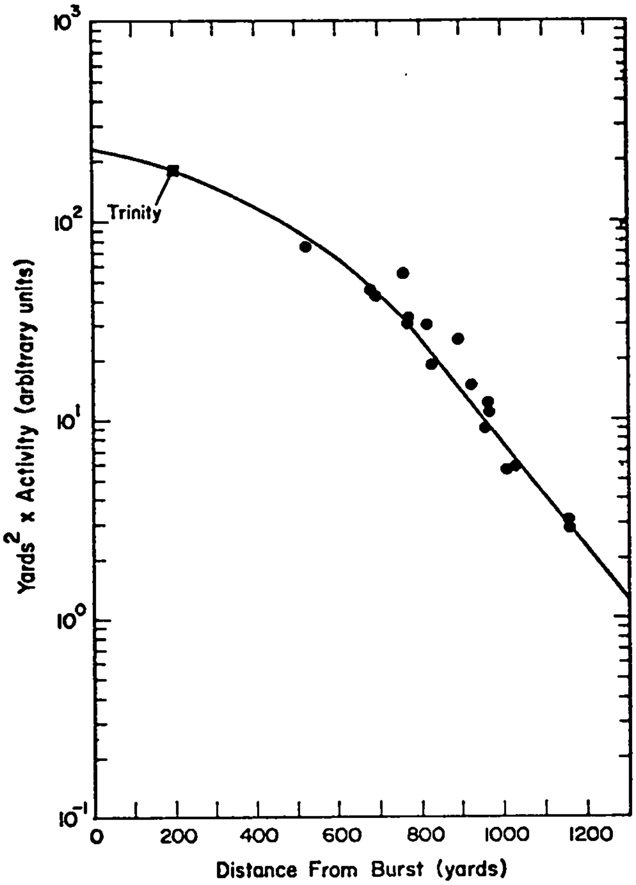

Fig. 2.
Experimental results of prompt neutron measurements.

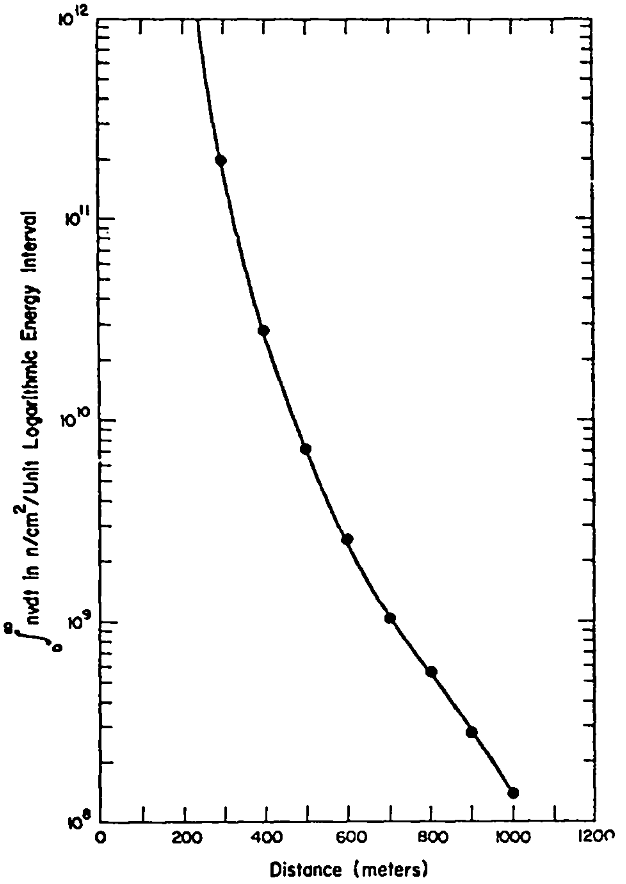

Fig. 3.
Slow neutron flux vs. distance.

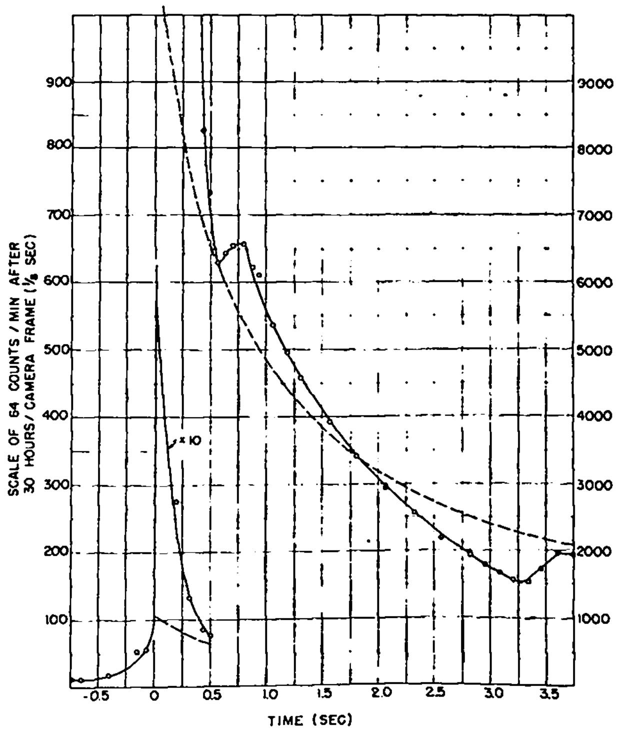

Fig. 4.
Slow neutron flux vs. time.

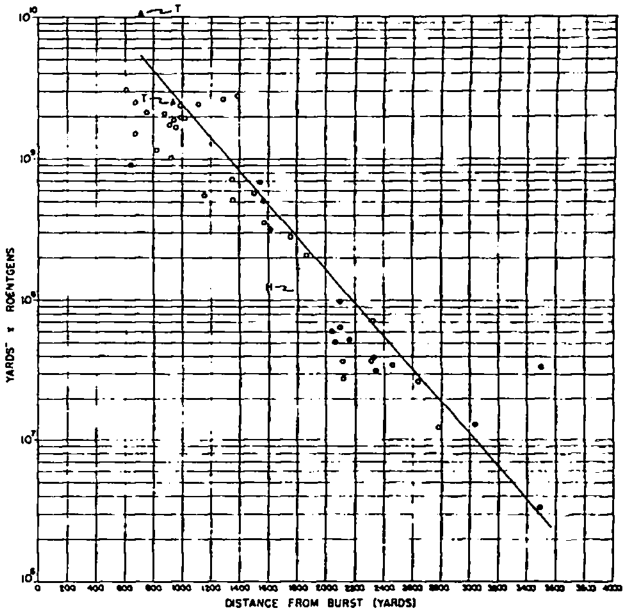

Fig. 5.
Bikini and Trinity radiation film results.

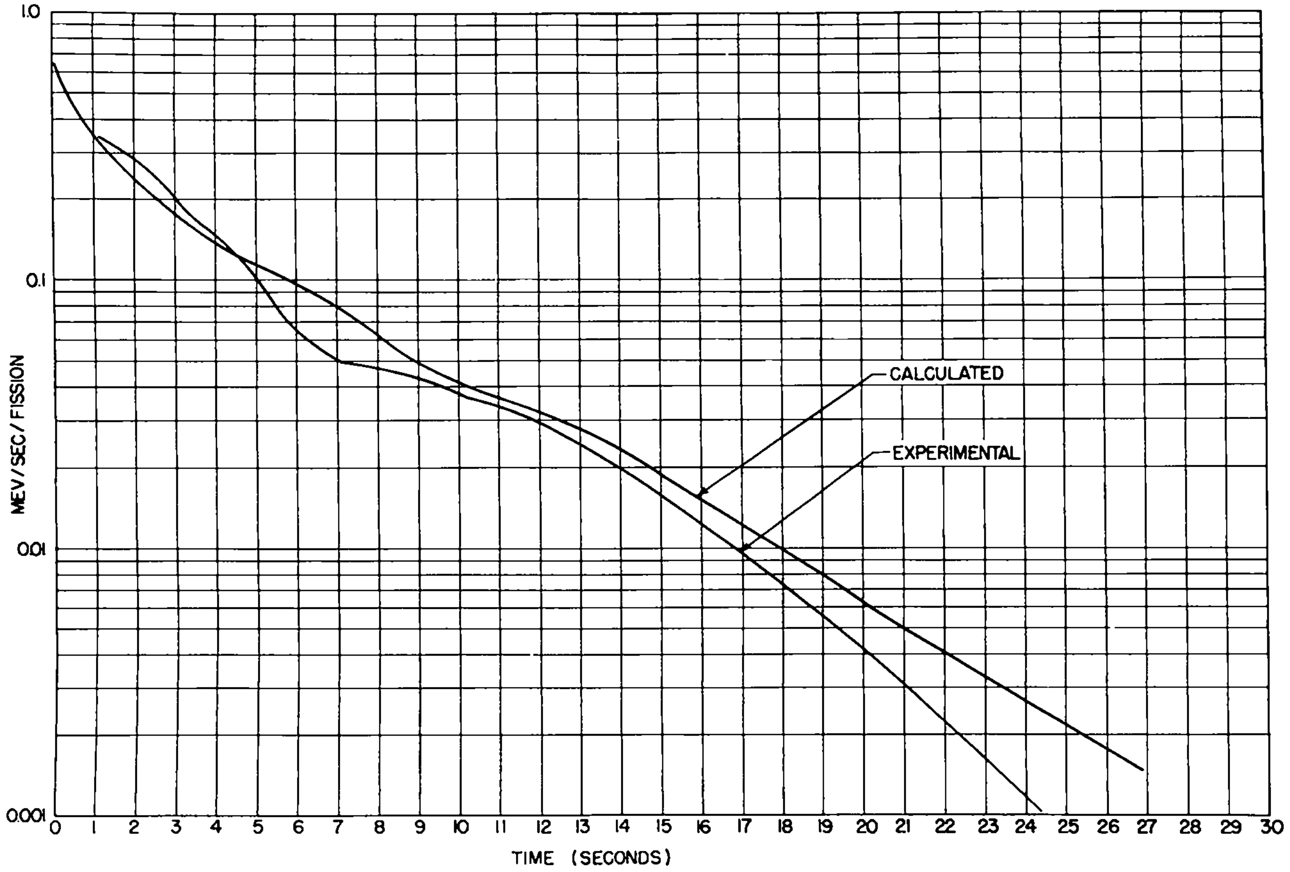

Fig. 6.
Calculated and experimental measurements of radiation intensity vs. time.

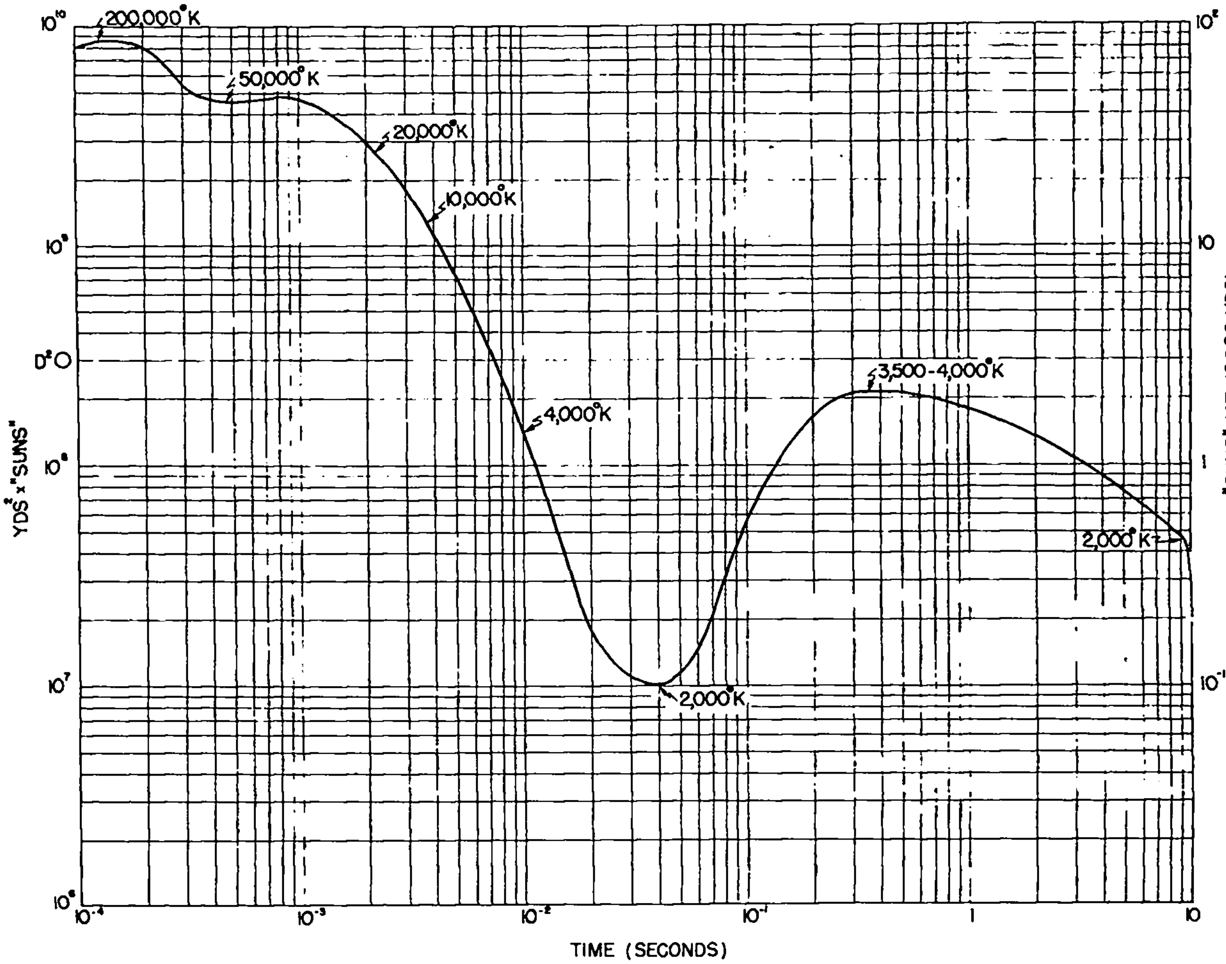

Fig. 7.
Illumination as a function of time.

7. SUMMARY OF NUCLEAR PHYSICS MEASUREMENTS (ROBERT R. WILSON)

The immediate purpose of the nuclear physics measurements was to determine the efficiency of the fast chain reaction to be tested at Trinity. The experiments were also designed in a manner that would give the greatest insight into the nuclear phenomena occurring during the explosion. Particularly in the event of a failure or of a resulting low efficiency would such measurements be crucial.

The experimental problems posed were extremely difficult. Most measurements were designed to give results for an efficiency varying from that equivalent to an energy release from 10 000 to 50 000 tons of TNT. It was necessary to place most of the equipment in a position where it had to withstand the heat and shock wave from the bomb, or alternatively to send its data to a distant recording station before it was destroyed. We can understand the difficulty of transmitting signals during the explosion when we consider that the gamma rays from the reaction will ionize the air and other material within hundreds of yards. Fermi has calculated that the ensuing removal of the natural electrical potential gradient in the atmosphere will be equivalent to a large bolt of lightning striking that vicinity. We were plagued by the thought that other such phenomena might occur in an unpredictable or unthought of manner. All signal lines were completely shielded, in many cases doubly shielded. In spite of this many records were lost because of spurious pickup at the time of the explosion that paralyzed the recording equipment. Much of the recording was done photographically in reinforced concrete, earth-covered shelters placed about 1000 yd from the bomb. Deeply buried shielded cables brought the signals to the shelters. Even here the tremendous gamma-ray emission blackened the photo plates except where the plates were surrounded by thick lead shields within the shelters. In many cases the dirt was blown from the shelters by the outgoing wind.

It was difficult to keep the number of experiments within bounds. Most physicists yielded to temptation and conceived experiment after experiment. A screening board consisting of E. Fermi, V. Weisskopf, and R. Wilson considered each proposed experiment with respect to its feasibility and possibility of giving cogent information. Even so, considering the short time in which to prepare the experiments, perhaps too many were attempted.

The theoretical work by V. F. Weisskopf on what nuclear phenomena might be produced by the fast chain reaction was of great assistance to those designing the experiments.

It was recognized from the beginning that the most promising measurement of the nuclear efficiency would come from the radiochemical determination, and hence the greatest effort was put into this experiment under Anderson's direction. Experimental details will not be given here.

Segre's group made observations on the delayed gamma rays from the fission products by means of ionization chambers several milliseconds after the explosion. They had two stations: one on the ground at 550 m from the bomb and another one at the same distance but lifted by a balloon to an elevation such that the line joining the balloon with the bomb made a 45° angle with the horizontal. The purpose of the latter station was to get away from the effects due to the earth thrown into the air by the explosion. Unfortunately the airborne detector was destroyed by the initial radiation flash before a record was obtained. In addition to the ionization chamber measurements they also made measurements of the total radiation in gamma units at various distances from the bomb and under several amounts of lead shielding, using the blackening of photographic materials.

Moon also made measurements on the delayed gamma rays at longer times,[11] particularly for the purpose of giving information to parties entering the radioactive region after the explosion. He also made an attempt to photograph the distribution of fission products in space as a function of time using the gamma rays from the products and pinhole camera.[15]

The radiant energy was successfully measured by D. Williams and P. Yuster using a thermopile technique.[12] They found 3060 metric tons of TNT equivalent as the value for the total radiant energy emitted.

The members of J. William's group made measurements on the number of delayed neutrons from the fission products resulting from the explosion. Their technique consisted of measuring the activity of a cellophane tape that had been passed rapidly between two ^{235}U plates. The activities of the fission fragments caught in the cellophane gave a time-differentiated neutron record. Three cellophane catcher cameras were constructed. One was airborne 300 m out and 300 m up; the other two were ground stations, one at 300 m and the other at 600 m from the bomb. Only the 600-m station survived the radiation and the blast to give record.

The low and unknown density distribution in the ball of fire and the large soil effect at 600 m made difficult the interpretation of the observed neutron density in terms of efficiency. A scaled mockup of the ground plus ball of fire hole has been studied, and the results indicated that at 600 m the hole produced by the ball of fire nearly compensated for the reduction in intensity produced by the soil.

E. Klema determined the number of neutrons per square centimeter per unit logarithmic energy interval as a function of distance from the bomb by measuring the activation of cadmium-covered gold foils which had been calibrated in a graphite block. His values were in good agreement with those obtained by the catcher camera technique after the latter had been integrated over the time. Klema also measured the number of fast neutrons from the nuclear explosion at a point 200 m distant using sulphur as the detector.

Both in the case of delayed neutron measurements and of delayed gamma-ray observations, more reliable results would have been obtained had the nuclear efficiency been somewhat lower.

8. SUMMARY OF MECHANICAL EFFECTS (J. H. MANLEY)

8.1. 100-Ton Test and July 16th Nuclear Explosion

To have a summary of mechanical effects for easy reference, the data from various reports on both the 100-ton test and the July 16th nuclear explosion have been collected in Tables II and III. These data are also shown graphically in Fig. 8.

The data have been selected in the sense that uncertain values have been omitted, and in some cases of apparently equal weight an average has been used in tabulation. Occasionally more than one value by a single method appear at a given radius. These derive from equipment at different directions from the explosion. The difference in results for these cases is not great enough to suggest a significant asymmetry in the explosion. For complete details and description of the instrumentation, the orginal reports as indicated in Tables II and III should be consulted.

TABLE II

AIR BLAST

July 16th Nuclear Explosion		100-Ton Test
Mechanical Impulse Gauge:		
Radial position	1200 yd	200 yd
Peak pressure	9.4 ± 15% psi	15 psi
Impulse	1.77 ± 6% psi-s	0.426 psi-s
Duration	0.65 ± 5% s	0.130 s
Condenser Gauge:		
Radial position	6000 yd	No record
Peak pressure	0.58 ± 0.03 psi	
Impulse	0.45 psi-s	
Microbarographs:		
Radial Position (10^{-3} yd)	**Peak Pressure (psi)**	
10.0	0.47	Not used
13.4	0.31	
15.5	0.13	
48.3	0.03	
50.0	0.11	
60.5	0.04	
63.3	0.03	
78.	0.008	

July 16th Nuclear Explosion

100-Ton Test

Piezo Gauges:

No record

Radial Position (yd)	Peak Pressure (psi)	Impulse (psi-s)
150	20.4	---
180	14.2	---
230	8.2	.470
230	9.0	.556
320	5.9	.346
740	1.6	.172
1500	0.73	.073
9200	0.13	.015

Excess Velocity:

Radial Position (yd)	Peak Pressure (psi)
448.7	45.2
593.2	25.3
593.3	27.2
838.4	14.0
838.4	12.2
1185.1	7.0
1184.9	7.1

Radial Position (yd)	Peak Pressure (psi)
164	16.2
204	10.2
204	11.0
272	6.3
498	2.2

Piston Gauges:

Radial Position (yd)	Peak Pressure (psi)
367	>60
500	24 - 26
567	<18
1000	2.6 - 6.7
1500	3.5 - 4.0
2000	>2.8

Not used

July 16th Nuclear Explosion

Foil Gauges:

Radial Position (yd)	Peak Pressure (psi)
800	6.18 - 7.35
814	6.18 - 7.35
1000	6.18 - 7.35
1190	5.09 - 6.18
1250	6.18 - 7.35
1250	5.09 - 6.18
1320	5.09 - 6.18
1360	6.18 - 7.35
1360	5.09 - 6.18
1400	3.96 - 5.09
1400	5.09 - 6.18
1445	5.09 - 6.18
1445	6.18 - 7.35
1490	3.96 - 5.09
1490	5.09 - 6.18
1550	5.09 - 6.18
1550	6.18 - 7.35
1620	3.96 - 5.09
1710	3.96 - 5.09
1800	2.97 - 3.96
1800	3.96 - 5.09
1920	2.97 - 3.96
1920	3.96 - 5.09
2050	2.97 - 3.96
2250	2.10 - 2.97
2550	2.10 - 2.97
2675	2.10 - 2.97

Crusher Gauges:

Radial Position (ft)	Max. Pressure (tons/sq. in.)
327	1.10
328-1/4	1.34
320-1/4	1.26
322	1.36
208	4.95

100-Ton Test

Radial Position (yd)	Peak Pressure[a] (psi)
195	10.5 - 11.8
220	10.0 - 11.2
270	7.4 - 7.7
360	4.0 - 4.6
520	2.0 - 2.6

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[a] Range given in lowest value of Table V, column 6 to highest value Table V, column 7, p.10 of LA-354.

Not used

TABLE III

EARTH MOVEMENT

Geophones:

July 16th Nuclear Explosion			100-Ton Test		
Radial Position (yd)	Max Displacement (cm)		Radial Position (yd)	Max Displacement (cm)	
	Hor.	Vert.		Hor.	Vert.
800	---	1.2	800	.030	.033
1500	.75	---	1500	.010	.018
	(.52)[a]	(0.36)			
9000	.019	.02	9000	.0018	---
				(.0033)	(.0028)

---

[a] Values in parentheses were obtained at approximately 150° from other values listed. These are derived results (from velocity and periods) and are accurate to about 50%.

Seismographs:

July 16th Nuclear Explosion		100-Ton Test
Radial Position (yd)	Max Displacement (cm)	
	Hor.-Radial	Not used
9000	0.068	

The most extensive data on *both* explosions was obtained from the excess velocity measurement and from foil gauges. Neither method gives as precise information as desired: the velocity method involves an average between two distances, the foil method involves discrete pressure increments. However, by scaling the results of the 100-ton test (108-tons TNT equivalent neglecting any effects of wood boxes) one has:

Method	Nuclear Explosion, TNT Equivalent (tons)
Foil gauges	9900 ± 1000
Excess velocity	10 000 ± 1000

Measurements of earth motion show that earth shock is unimportant as a damage-producing agent in comparison with air blast. Different methods of scaling test results give values from 3000 to 15 000 tons TNT equivalent for the nuclear explosion.

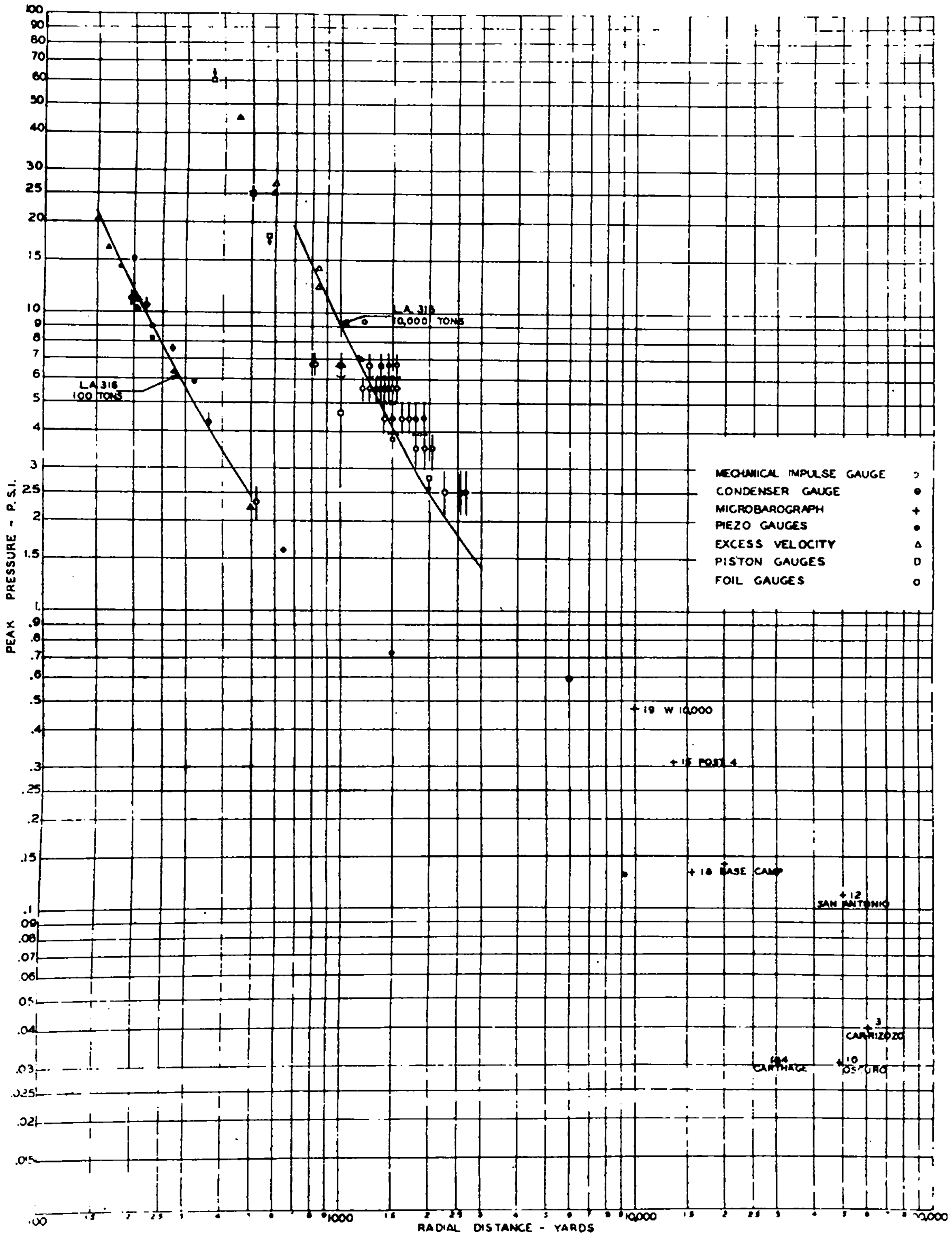

Fig. 8.
Data for 100-ton test and for the July 16th nuclear explosion.

9. JULY 16TH NUCLEAR EXPLOSION—SUMMARY OF OPTICAL OBSERVATIONS (JULIAN MACK)

9.1. Introduction

The observations of the Optics group fall roughly into two categories: space-time relationships[16] and the analysis of the emitted light.[12] A semipopular account of the explosion, in titled pictures, has been issued.[17]

9.2 Space-Time Relationship

For the determination of space-time relationships, approximately 10^5 photographic exposures were made, almost all of them motion picture frames. Most of the resultant data are shown in Fig. 9 (Ref. 16). A summary of the events observed follows. The expansion of the ball of fire before striking the ground was almost symmetric, following the relationship

$$R = 616\, t^{2/5}$$

where R is the radius in meters and t is the time in seconds, except for the extra brightness and retardation of a part of the sphere near the bottom, a number of blisters, and several spikes that shot radially ahead of the ball below the equator. Contact with the ground was made at 0.65 ± 0.05 ms. Thereafter the ball became rapidly smoother. From 1.5-32 ms the time dependence of the shock radius closely followed the relationship

$$R = 564\, (t + 4 \times 10^{-4})^{2/5}$$

At 3 ms there appeared at the bottom of the ball an irregular line of demarcation, below which the surface was appreciably brighter than above. This line rose like the top of a curtain until it disappeared at the top of the ball at about 11 ms. Shortly after the spikes struck the ground (about 2 ms) there appeared on the ground ahead of the shock wave a wide skirt of lumpy matter and within and above the skirt a smooth belt (interpreted as the Mach wave), originally brighter than the main wave but rapidly growing dimmer. Two successive visible fronts dropped behind the well-defined shock wave. The brighter but less sharply limited ball of fire fell behind it at about 16 ms (105 m). At about 32 ms (144 m) there appeared immediately behind the shock wave a dark front of absorbing matter, which traveled slowly out until it became invisible at 0.85 s (375 m). The shock wave itself became invisible at about 0.10 s (2.4×10^2 m) but was followed thereafter to 0.39 s (460 m), first by its light-refracting property and later by the momentum it imparted to a balloon cable.

The ball of fire grew even more slowly to a radius of about 3×10^2 m, until the dust cloud growing out of the skirt almost enveloped it. The top of the ball started to rise again at 2 s. At 3.5 s a minimum horizontal diameter, or neck, appeared one-third of the way up the skirt, and the portion of the skirt above the neck formed a vortex ring. The neck narrowed, and the ring and fast-growing pile of matter above it rose as a new cloud of smoke, carrying a convection stem of dust behind it. A boundary within the cloud, between the ring and the upper part, persisted for at least 22 s. The stem appeared twisted like a left-handed screw. The cloud of smoke, surrounded by a faint purple haze, rose with its top traveling at 57 m/s, at least until the top reached 1.5 km. The later history of the cloud was not quantitatively recorded.

Data not shown in Fig. 9 include quantitative measurements on the refraction of light and the material velocity behind the shock front, in certain intervals; the former can be made to yield the material density as a function of radius behind the shock front.[16]

9.3 Analysis of the Emitted Light

For the analysis of the emitted light, we have density readings on motion-picture negatives, quartz-prism spectrograms for the first few milliseconds with time resolution of the order of 10^{-5} s and for the first 1/5 s with lower resolution, photocell records (partly usable) of the light intensity for the first second, and thermopile records showing that the total radiant energy density received at 10^4 yd was 1.2 x 10^7 ergs cm^{-2} ± ~ 15%.

The following observations, among others, seem to deserve special notice.

- During the earliest stages observed by us (radius α 10 to 100 m) the shock wave radius followed Taylor's two-fifths power law: radius times 2/5.
- The shock wave was markedly deformed by the platform; moreover, the radius in other directions was influenced by the presence of the platform.[5]
- A skirt of hot, lumpy matter, thus far unexplained, rose from the ground ahead of the Mach wave.
- The Mach wave was clearly discernible throughout the interval ~10^{-2} to 10^{-1} s, and information is available on its kinematics and on its brightness, opacity, and material density.
- The dropping of the ball of fire behind the shock wave produced a minimum in the brightness curve, as predicted. (Theory discussed in Ref. 5.)
- The shock wave was followed, at an increasing time interval as its pressure and temperature decreased, by a sharply defined dark wave front of absorbing material, evidently consisting of one or more of the colored oxides of nitrogen; the dark wave broke away from coincidence with the shock wave at about 144 m, and grew asymptotically to a radius of about 360 m before it became indiscernible.
- The velocity of the shock wave unexpectedly remained nearly constant at twice sound velocity during the expansion in radius from 2.5 x 10^2 to 4 x 10^2 m, decreasing by only 15% in this interval instead of dropping nearly to the ordinary velocity of sound. Whereas a slight increase in sound velocity might have been expected from the sudden heating of the air around the ball of fire by radiation, the predominant cause of the observed maintenance of velocity appears to be radiant heating of the shock front by energy absorbed by the dark front as ultraviolet or visible radiation and transformed there to lower frequencies, as suggested by Magee.
- The emission spectrum had a violet cutoff that was a function of time; the highest wave number emitted at any time was 3.34 x 10^4 cm^{-1}, which coincides, within the error of the determination, with the cutoff characteristic of ozone formation.

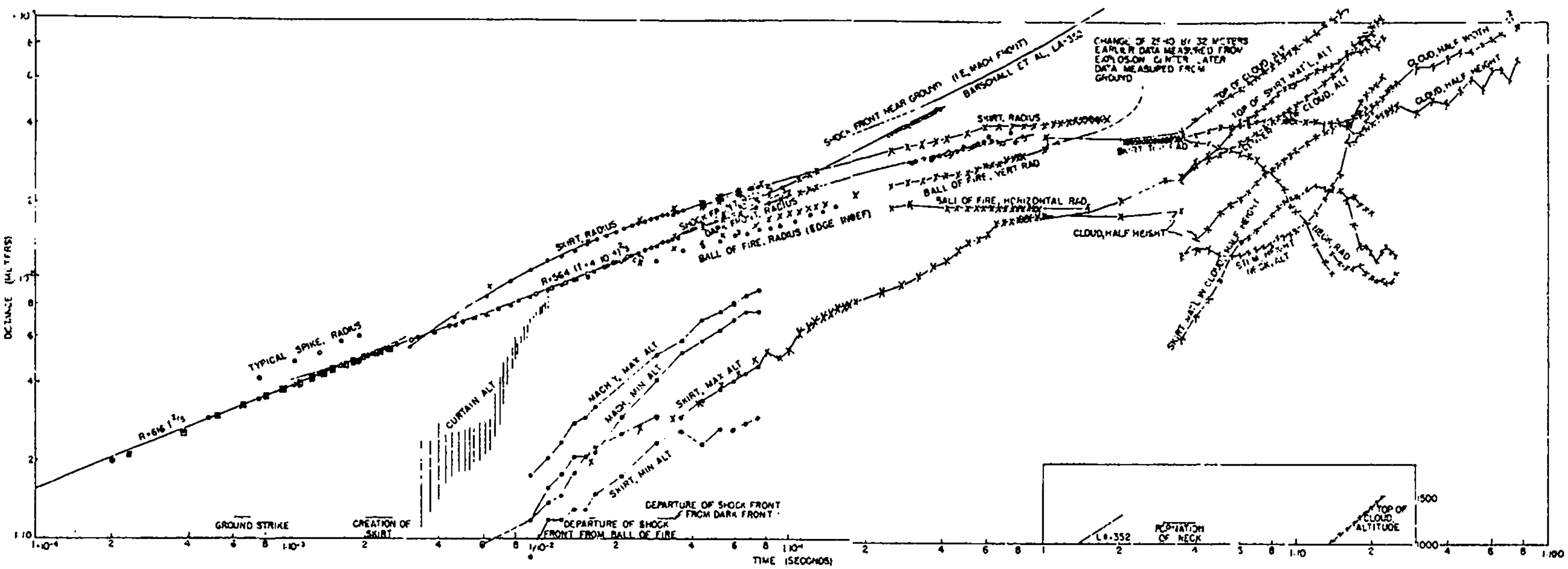

Fig. 9.
Summary of optical space-time data.

⊡ *8mm, 7110/s. W 800 F = 2 in.*
Θ *16mm, 3560/s. W 10,000 F = 6 in.*
• *16mm, 655/s. N 10,000 F = 6 in.*
× *35mm, 107/s. N 10,000 F = 18 in.*
\+ *35mm, 24/s. N 10,000 F = 3 in.*
⊗⊗ *35mm, 119/s. W 10,000 F = 24 in.*

10. SUMMARY OF TRINITY EXPERIMENTS AND INDEX OF REPORTS (K. T. BAINBRIDGE)

TRINITY EXPERIMENTS

Measurements	In Charge	Equipment or Method
I. IMPLOSION		
(1) Detonator Asimultaneity	K. Greisen E. W. Titterton	Detonation wave operated switches and fast scopes
(2) Shock wave transmission time	D. Froman R. Sutton	Interval from firing of detonators to nuclear explosion recorded on fast scope
(3) Multiplication factor (α)	R. R. Wilson	(a) Electron multiplier chambers and time expander
	R. R. Wilson	(b) Two-chamber method
	B. Rossi	(c) Single coaxial chamber, coaxial transformers and direct deflection high-speed oscillograph
II. ENERGY RELEASE BY NUCLEAR MEASUREMENTS	R. R. Wilson	
(1) Delayed gamma rays	E. Segre	Ionization chambers, multiple amplifiers, Heiland recorders, ground and balloon sites
(2) Delayed neutrons	H. T. Richards	(a) Cellophane catcher and 25 plates, on ground and airborne
		(b) Gold foil detectors to give integrated flux
		(c) Sulphur threshold detectors 8 units
(3) Conversion of plutonium to fission products	H. L. Anderson	(a) Determination of ratio of fission products to plutonium
	D. Frisch J. M. Hubbard	(b) Collection of fission products and plutonium or 25 on filters from planes at high altitude
III. DAMAGE, BLAST, AND SHOCK	J. H. Manley	

Blast	J. O. Hirschfelder	
(1) Piezo	R. L. Walker	Quartz piezo gauges—22 units
(2) Condenser	W. C. Bright	(a) Condenser gauges, frequency modulation type C.I.T.—8 units
	B. Waldman	(b) Condenser gauges, C.I.T. type dropped from B-29 planes—6 units, 2 planes
(3) Excess velocity	H. H. Barschall	(a) Moving coil loudspeaker pickup—10 stations
		(b) From piezo time records
	J. E. Mack	(c) Optical method, Blast-operated switches and torpex flash bombs
	J. E. Mack	(d) Schlieren method—one station
(4) Peak pressure	H. Sheard D. Littler	(a) Spring-loaded piston gauges—8 units, intermediate pressure range 2.5- 10 psi
	H. Sheard D. Littler	(b) Same gauges—12 units, above ground and in slit trenches, 20- 150 psi in range
	W. G. Penney F. Reines	(c) Crusher-type gauges
	J. C. Hoogterp	(d) Aluminum diaphragm "box" gauges—52 units 1- to 6-lb range
(5) Remote pressure barograph recorders	J. H. Manley	19 Friez ML-3-A No. 792 barographs
(6) Impulse gauge	T. Jorgensen	12 mechanically recording piston liquid and orifice gauges, 4 each for 3 yield values
(7) Mass velocity	J. E. Mack	Suspended primacord and magnesium flash powder viewed by Fastaxes
(8) Shock wave expansion	(H. Bethe) J. E. Mack	Fastax cameras at 800-yd stations

Earth Shock	J. H. Manley	
(1) Geophone	H. M. Houghton	12 velocity-type moving coil strong motion geophones
(2) Seismographs - Leet	L. D. Leet	Five Leet three-component strong motion displacement seismographs
(3) Permanent earth displacement	W. G. Penney F. Reines	Steel stakes for level and vertical displacement measurements
(4) Remote seismographs	G-2	Tucson, El Paso, Denver observations
Ignition of Structural Materials		
(1) Roofing and wall materials	W. G. Marley F. Reines	Roofing, wood, and excelsior on stakes
IV. GENERAL PHENOMENA		
(1) Behaviour of ball of fire	J. E. Mack	(a) Six 8000 frames/s Fastaxes
		(b) Two 4000 frames/s Fastaxes
		(c) Two 800 frames/s Fastaxes
		(d) Fifteen color cameras, standard 16 mm
		(e) One Cline-Special 24 frames/s
	Lt. C. D. Curtis	(f) Two SCR-584 radars
(2) Rise of column	J. E. Mack	(a) Four 100 frames/s Mitchells, one 24 frames/s 16 mm
		(b) Two pinhole cameras
and ball of fire	P. B. Moon	(c) Two gamma-ray cameras
(3) Mushrooming and lateral movement	J. E. Mack	(a) Two Fairchild 9- by 9- in. aero view cameras at N-10 000 and W-10 000
		(b) Two Fairchild cameras 20 mi NE for stereo-photos

		(c) Two Fairchild cameras 20 mi E for stereo-photos
and rise of column	Capt. M. Allen	(d) Day or night position plotting by searchlight equipment
(4) Blast cloud effects	F. Reines analysis	J. E. Mack photos J. Aeby photos
Radiation Characteristics		
(1) Spectrographic	J. E. Mack	Two Hilger high-time resolution 10^{-5}-s spectrographs Two Bausch & Lomb spectrographs
(2) Total radiation	D. Williams J. E. Mack	Two thermocouples and recording equipment
(3) Photometric	J. E. Mack	Two units—moving film and filters Six photocells and filters recording on drum oscillograph
V. POSTSHOT RADIATION MEASUREMENTS		
(1) Gamma-ray sentinels	P. B. Moon	Sixteen ionization chambers which recorded at 10 000 yd shelters
(2) Portable chamber observations in high-gamma flux region	H. L. Anderson	Observations were made from the tanks using portable ionization chambers, standard design
(3) Dustborne product survey	L. H. Hempelmann	Portable alpha, gamma ionization chambers and Geiger counters
(4) Airborne products	J. M. Hubbard D. Frisch	B-29 planes equipped with special air filters
(5) Detailed crater survey	P. B. Moon	Ionization chambers and Watts- type amplifiers
VI. METEOROLOGY	J. M. Hubbard	Complete instrumentation and weather information

RESULTS

	July 16 Nuclear Explosion		100-ton Test
Results	Report	In Charge	Report
Records fogged by gamma rays.			
Equipment Test		M. Blair	
Record obtained from 600-m station. Energy release consistent with H. Anderson figure.			
Number of neutrons per cm^2 per unit logarithmic energy interval was measured for 7 stations, 300-1000 m.			
Two of 8 units recovered. Given flux for energies 3 MeV at 200 m			
Tracer Test 18 600 tons TNT		Anderson Sugarman	LA-282 LA-282A LA-290
No results from TR shot dust after it circled world. Indications from Hiroshima; nothing from Nagasaki.			
General blast considerations	LA-316	W. D. Kennedy	LAMS-247
No records. Traces thrown off scale by radiation effects.	LA-366	Walker	LA-286
No TR records. Shot had to be fired when planes out of position. 100-ton records and combat records		Waldman	
Obtained velocity of sound for a small charge and then excess velocity for bomb. Yield 10 000 tons		Barschall	LA-291
Blast pressure values low compared with all other methods		Not armed	
Highest pressure range	LA-431		

9900 ± 1000 ton TNT equivalent	LA-354	Hoogterp	LA-288
Consistent with 10 000 ton	LA-360		
Consistent with 10 000 ton	LA-355	Jorgensen	LA-284
19 000-ton *total* yield			
Extrapolation from small charge and 100-ton data gives 7000 ton	LA-351	Houghton	LA-287
Approximately 15 000 ton	LA-438	L. D. Leet prognosis	LA-439
10 000 ± 5000 ton	LA-365 LA-365A	Penney	LA-283 LA-292
No effect at these distances	None	See Leet report	LA-439
Risk of fire produced by radiant energy is small	LA-364		
(General prospectus)	LAMS-165 LA-531		
Two plots of cloud obtained. Radar reflection not favorable.	LA-430		
The first 18 mi of the main cloud path height was triangulated	LA-448 LA-531 LA-353	J. E. Mack	
These units were extremely valuable in giving the distribution of radioactive products immediately after the shot until safe stable conditions were assured		Moon	Trial for blast effects only
About 4 h after shot ionization data from the chambers were radioed back to the control shelter		Anderson Hempelmann	Trial of tanks and rockets

Local TR ionization and at remote points to 200 mi was measured for dust-deposited fission products	LAMS-277		
See Sec. 10, II. 3. b	LA-418		
After 4 wk, approx 15 R/h at edge of scoured crater, 0.02 R/h at 500 yd	LA-359	Anderson	LA-282 LA-282A LA-290
See complete report. Weather data obtained up to 45 min prior to shot at Point 0 to 20 000 ft and 25 min after shot. Low-level smoke studies made in event of a fizzle.	LA-357	Hubbard	LA-285

11. RECOMMENDATIONS FOR FUTURE OPERATIONS (K. T. BAINBRIDGE)

11.1 Measurements

These recommendations are made on the basis that the gadget under test incorporates some radical changes in design from the Model 2 used at Trinity and at Nagasaki. Therefore, the most important measurements of the test will be those concerned with the internal behavior of the gadget and the measurements of its energy release. Two cases should be considered—a ground test and an airdrop test over ground.

A ground test has the advantage of giving the maximum amount of information concerning the behaviour of the gadget, and it would permit fundamental physics experiments to be carried out which could only be conducted at great cost in time and personnel or could not be conducted at all if an airdrop test were made.

There have been newspaper accounts that the Navy has definitely decided on the tests of one or more gadgets from the stockpile. If this program goes through, then in addition to the measurements recommended for an airdrop test it would be useful to plaster the Navy ships inside and out with gold foil, sulfur, and ^{235}U neutron detecting equipment and equivalent films and automatic recording ionization chambers for gamma rays. These should be buoyant and recoverable in the event the ships so treated are sunk during the test.

11.1.1. Ground Test. The recommendations for experiments which should be included in the ground test are as follows (for details refer to the corresponding numbers in the chart on experiments for the July 16th nuclear explosion, Sec. 10).

Blast	Changes or Remarks
I. IMPLOSION	
(1) Detonator asimultaneity	---
(2) Shock wave transmission time	---
(3) Multiplication factor (b,c)	Three sets of equipment for maximum accuracy at different generation times.
II, ENERGY RELEASE (by nuclear measurements)	
Prompt gamma *and* delays. Total gamma irradiation	More for medical reasons. Not used in Trinity test.
(2) Delayed neutrons (a,b,c)	---
(3) Conversion of plutonium to fission products	---
a. On ground	---
b. In air	Extension over TR program
III. DAMAGE, BLAST, AND SHOCK <u>BLAST</u>	
(1) Piezo gauges	Thermally insulated by concentric aluminum foil shells

(2) Condenser gauges a. On ground b. Dropped from airplanes	The number cannot be increased over that planned for the TR test because of crowding of radio channels. If it is desired to increase the number of gauges, then considerable development will have to be done.
(3) Excess velocity	This was one of the most successful blast measuring methods (a)
(4) Peak pressure (a,b,c,)	Many more of these gauges should be used if they can be developed into reliable instruments
	Inexpensive and reliable (d)
(5) Remote pressure barograph recorders	Necessary for legal reasons
(6) Shock wave expansion	From ground sites, and from airplanes for practice for future tests
EARTH SHOCK	
(2) Seismographs—Leet	Necessary for legal reasons
(3) Permanent earth displacement	This is a simple measurement and is of interest because of the new phenomena encountered in the July 16 test
(4) Remote seismographs	The reverend seismographers will never forgive you if you do not give them a warning of the test.
IGNITION OF STRUCTURAL MATERIALS	The Army, the Navy, and de Seversky will want to define this.
IV. GENERAL PHENOMENA	
(1) Behavior of ball of fire (a,b,c,d,e)	These photographic records are extremely valuable, and this part of the work should certainly be expanded
(2) Rise of column (a)	
(3) Mushrooming and lateral movement (a,b,c,d,)	

Radiation Characteristics	
(2) Total Radiation	
V. POSTSHOT RADIATION MEASUREMENTS	
(1) Gamma-ray sentinels	---
(2) Portable chamber observations in high-gamma flux region	---
(3) Dustborne product survey	---
(4) Airborne products	See II.3.b.
VI. METEOROLOGY	Vitally important, and the sooner the group starts at a new site, the better.

Additional suggestions by P. B. Moon follow.

1. "That ionization sentinels, signalling by radio instead of by line, be taken out and deposited in the field *after* the shot in addition to those of the previous type that were installed before the shot. In this way readings could be obtained from the area of the crater. The sentinels could be taken out by the lead-lined tanks. This suggestion was made to me by F. Oppenheimer.

2. "That in order to elucidate the remarkable fogging of films buried 5 ft underground, specimens of suitable neutron-activatable and gamma-activatable radioactive indicators be buried at various depths and distances and recovered for examination after the shot. This suggestion was appended by me to the LA-430 (Ref. 15) report on our attempts to obtain gamma-ray kinephotographs.

"Weisskopf has since suggested that photographic films might also be buried."

11.1.2. Airborne Drop Test. Recommendations for tests which from past experience could be accomplished for an airborne drop are as follows. Numbers correspond to those in Sec. 10.

Blast	**Changes or Remarks**
I. IMPLOSION	
(1) Detonator asimultaneity	This is difficult and was not licked in the period November 1944—July 1945.
(2) Shock wave transmission time	This could be handled by an amplitude-modulated transmitter. A continuous low-amplitude signal from the bomb would give a recorder something to tune on; the first detonator increases the amplitude; the explosion kills the transmitter entirely.
(3) Multiplication factor (α)	No airborne scheme has yet been suggested that could compete with the Rossi method on the ground or in the air. The two-chamber method might be feasible.

II. ENERGY RELEASE (by nuclear measurements)	
(3) Collection of fission products and plutonium or 25 on filters from planes at high altitude	See Ref. 18.
III. DAMAGE, BLAST, AND SHOCK	
BLAST	
(2) Condenser gauges (a,b)	---
(4) Peak pressure (d)—aluminum-diaphragm box gauges	This is an inexpensive and reliable method for blast measurement.
(5) Remote pressure barograph recorders	Necessary for legal reasons.
(8) Shock wave expansion	If possible, airborne and ground-located cameras.
EARTH SHOCK	
(1) Geophones	For scientific interest.
(2) Seismographs - Leet	For legal reasons.
IGNITION OF STRUCTURAL MATERIALS	
IV. GENERAL PHENOMENA	Important and should be expanded.
(1) Behavior of ball of fire (a,b,c,d,e)	
(2) Rise of column (a,b)	
(3) Mushrooming and lateral movement (a,b,c)	
V. POSTSHOT RADIATION MEASUREMENTS	
(1) Gamma-ray sentinels	One set in place; one set introduced afterwards.
(3) Dustborne product survey	---
(4) Airborne products	See II.3.b.
VI. METEOROLOGY	Extremely important.

11.2. Preparations and Administration

1. A firm directive should be obtained for a test at least 6 months in advance for operations within the continental limits of the United States. This assumes that a location for the test has been agreed upon.

2. A firm agreement should be obtained from the higher administration on personnel policy and the procurement of personnel. J. R. Oppenheimer gave 100% backing to the transfer policy he initiated.

3. It is essential to have a first-class man in charge of "services" and to have all services under one head. J. H. Williams did a supreme job in this work.

4. It is essential to have the base camp installations complete 4 months before the date of the test.

5. The wiring should be complete at the latest 1 month before the test, which means that 90% of the requirements should be known 4 months prior.

6. No new experiments should be introduced later than 6 wk before the test.

7. *No new equipment of any kind, electrical or mechanical, should be installed or removed after the first test rehearsal* except as required to minimize pickup and interference encountered in the first rehearsal.

8. An examination of the organization of TR-1, TR-2, TR-3, etc., will give a realistic estimate of the minimum number of men required per job and per experiment.

9. There should be increases in the timing staff. The large amount of testing and calibration made it very difficult for one man to carry the load. Both J. L. McKibben and E. W. Titterton were overloaded almost beyond human endurance for the period of 2 wk preceding the test. Eighteen hours a day, for 2 wk, is too much, and whoever takes their positions should have two aides with nothing else to do but keep up-to-date on the system and aid in the installation, test, and calibration work.

10. The same applies to whoever takes Sgt. Jopp's position; he was called upon day or night whenever any emergencies arose, such as broken wires, or when unauthorized and unreported splicing of wires was done by some irresponsible person in a hurry. Shooting is much too good for anyone who crosses up the wires. All changes in the wiring must be channelled through one office; in our case, Sgt. Jopp.

11. All shielding of equipment within a range of 1000 yd for a 20 000-ton gadget should be gas tight, and if earth covered, a concrete apron and shield must be provided. There is evidence at 300 yd that radioactive gases were blown into equipment and cooled and condensed there. At 800 yd earth embankments were scoured away, which decreased the shielding for delayed radiations.

12. Whoever has the overall responsibility for the test should insist on review power over any newspaper releases to make sure the facts, if any, are correct and to avoid the tripe and incorrect statements which appeared in the official release.

13. The FM Motorola radios are perfectly satisfactory day and night within a 15-mi radius, and there are many cases where they did good duty up to 40 mi. However, for any distances greater than 15 mi, sufficient radios of the SCR-299 type, or lighter models if possible, should be used.

14. All instruments should be started automatically by remote control. No one should have to throw any switches after the arming switches and timing sequence switches have been closed.

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